PATENT SPECIFICATION

797,574

Date of Application and filing Complete Specification: July 24, 1956.
No. 22907/56.
Application made in United States of America on July 25, 1955.
Complete Specification Published: July 2, 1958.

Index at acceptance:—Classes 51(1), BA(8L: 26); and 123(2), A(8C: 8G1: 9B2).
International Classification:—F22b. F23c.

COMPLETE SPECIFICATION

Improvements in or relating to method and apparatus for Heating Fluids

We, OXY-CATALYST, INC., a corporation organized under the laws of the State of Pennsylvania, one of the United States of America, of 115 Conestoga Road, Wayne, State of Pennsylvania, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement.

This invention relates to a method and apparatus for indirectly heating fluids involving the use of a fluidized bed of oxidation catalyst.

Conventional systems for indirectly heating fluids such as for the generation of steam involve burning a fuel by flame combustion to generate hot combustion gases which are then passed over boiler tubes or other heat exchange surface through which a fluid flows whereby the heat is transferred from the gases to the fluid. It has been found that another approach, involving the use of a fluidized bed of oxidation catalyst, has many important advantages over such ordinary methods involving flame combustion. In accordance with this system, a fuel-air mixture is passed upwardly through a bed of relatively small particles of oxidation catalyst at a velocity adjusted to maintain the bed in a fluidized condition and under conditions such that the fuel undergoes catalytic oxidation within the bed. Tubes or other heat exchange surfaces are immersed within the bed and the fluid to be heated is passed through these tubes and thus absorbs heat from the bed.

Such a system has the following advantages over conventional flame combustion systems:

(1) High rates of heat release per unit volume of fluidized bed may be obtained, averaging often 20 to 30 times the rate of heat release per unit furnace volume in a flame combustion system. This results in substantial reduction in the size of the unit.

(2) A large area of heat exchange surface may be disposed within the fluidized bed where the oxidation of the fuel takes place in contrast to the conventional system in which the furnace volume is substantially empty. This makes possible further reduction in the unit size.

(3) High coefficients of heat transfer are obtained in the fluidized bed, averaging often from 3 to 7 times as high as those obtained in the convection section of ordinary boilers. This reduces the amount of heat exchange surface required and results in still further reduction in the size of the unit.

(4) In contrast to flame combustion where maximum temperatures of the order of 3000°—3500° F. are obtained, the release of heat of the fuel in a fluidized bed of oxidation catalyst may be accomplished at temperatures well below flame temperatures, usually in the range of from 1000°—2000° F.

While having the advantages discussed above, it has been found that in commercial operations such a system presents a number of practical problems. One of the major problems is that of providing a system which will operate satisfactorily using a relatively low cost catalyst. Oxidation catalysts having reasonable activity are subject to attrition losses when employed in a fluidized bed where the catalyst particles are subject to continual impact with one another and with the tubes immersed within the bed. Such attrition results in the production of fine material well below the average particle size of the bed and these fines leave the bed in the stream of effluent gases. Such unavoidable losses prohibits the use of very highly active, high cost catalytic materials such as catalysts containing platinum and requires the use of less active, lower cost materials such as, for example, catalyst containing silver, copper, or chromium.

The use of such low cost, lower activity oxidation catalysts however is subject to the disadvantage that such catalysts reach a high level of activity only at relatively high temperatures such as 1000°—1500° F. Because of this characteristic, the rate of heat release within the bed falls to undesirably low levels when the bed temperature is allowed to drop below these temperatures, and the combustion air consequently must enter the bed at relatively high temperatures such as 1000° F. to insure stability of operation.

The requirement that the combustion air entering the bed be preheated to relatively high temperatures of the order of 1000° F. for example imposes a serious limitation on the practical application of the system since such preheat temperatures cannot be obtained in a practical manner entirely by heat exchange with the effluent gases. If an auxiliary flame burner is employed to supply sufficient hot combustion gases to raise the temperature of the air to the order of 1000° F. one of the basic advantages of this system is in effect partly defeated since a large auxiliary furnace must then be provided to burn by flame combustion a substantial portion, for example of the order of one-third of the total amount of fuel. Furthermore, the problem of mixing a large volume of hot gas from the auxiliary flame burner with the combustion air, and the problem of properly distributing the preheated mixture at a temperature of e.g. 1000°—1200° F. over the area of the fluidized bed so as to obtain uniform fluidization characteristics are problems which are difficult to solve in an economical fashion.

It is the object of the present invention to provide a method and apparatus which will permit the practical use of a fluidized bed of relatively low activity oxidation catalyst in the foregoing system without the necessity of resorting to a large auxiliary flame burner to provide the necessary preheat of the combustion air and without the accompanying problems of mixing the hot combustion gases from such auxiliary burner with the main air supply and of distributing the resultant high temperature mixture uniformly throughout the fluidized bed. Other objects of the invention will appear from the description which follows.

In accordance with the invention, a system is provided which comprises two beds of oxidation catalyst which are preferably arranged in superimposed relationship. The first or lower bed is relatively small in volume and is composed of oxidation catalyst of relatively high activity, such as a platinum type catalyst. This bed is arranged to undergo little or no movement such that the catalyst is not subjected to losses from attrition. This bed has substantially no heat exchange surface associated with it. The second or upper bed of catalyst is relatively larger in volume and is composed of oxidation catalyst of relatively low cost and of relatively lower activity than that in the first bed. This bed is arranged so as to undergo fluidization under normal operating conditions and is provided with tubes or other heat exchange surfaces which are immersed in the bed, and through which a fluid is circulated to absorb heat from the bed.

In the operation of this system, the main air supply with substantially no preheat, or preheated to relatively low temperatures such as 400°–600° F., is passed through the first bed of highly active catalyst together with a minor proportion of the total fuel, sufficient only to raise the temperature of the air to the order of 900°—1500° F. Catalytic oxidation of this portion of the fuel occurs in the first bed and the resultant effluent, thus preheated to the temperature required for proper operation of the second or fluidized bed, is mixed with the remainder of the fuel in the bottom portion of the fluidized bed. Catalytic oxidation of the major portion of the fuel thus occurs in the second bed and the heat released is transferred from the bed to the fluid flowing through the tubes immersed therein.

By operation in this manner, distribution of the air supply over the cross-sectional area occupied by the fluidized bed may be accomplished at the entry to the first or lower bed at a relatively low temperature, and the necessary degree of preheat may be imparted to the air supply in a convenient and economical manner in a relatively small volume of highly active catalyst which is not subject to the attrition losses inherent in the fluidized bed operation. As will be apparent from the more detailed description which follows, this type of operation also permits a flexibility in the operation of the fluidized bed which is not readily obtained with the use of a single bed system.

For a better understanding of the invention, reference is now made to the accompanying drawings in which Fig. 1 is a semi-diagrammatic view showing one preferred embodiment of the invention; and,

Fig. 2 is a section taken on the line 2—2 of Fig. 1; and

Fig. 3 is a semi-diagrammatic illustration of another preferred embodiment of the invention.

Referring now particularly to Figs. 1 and 2, the reference numeral 1 indicates a steel chamber having a refractory lining 2. In the lower portion of the chamber a perforated distributing plate 3 is provided, supported by brackets 4, which serves the dual purpose of distributing the combustion air entering the bottom of the chamber through line 5 uniformly throughout the cross-section of the chamber and of supporting the lower bed of oxidation catalyst made up of relatively large pellets 6 in shape of cylinders, for example, having a diameter and length of approximately $\frac{3}{8}$".

In order to insure the uniform distribution of the combustion air, it will generally be found necessary to take a substantial pressure drop across the distributing plate 3 or other equivalent means. In the case of a perforated plate for example, it has been found that the use of relatively small, closely spaced perforations are required to insure uniform distribution. Perforations 1/16" in diameter and spaced approximately on 1/8" centers have for example been found to provide satisfactory distribution for an air flow of approximately 13 lbs. per minute over a cross-sectional area of approximately one square foot.

The lower bed is, as previously stated, made up of a relatively high activity oxidation catalyst. Particularly suitable are catalysts containing platinum or palladium distributed in a finely divided condition upon a support composed of an activated metal oxide such as activated alumina, beryllia, thoria, magnesia or zirconia. Highly active and stable oxidation catalysts, for example, may be prepared by impregnating pellets of activated alumina with from 0.2% to 1% by weight of finely divided platinum. The impregnation may for example be carried out by soaking alumina pellets in a dilute solution of chloroplatinic acid, drying, and thereafter decomposing the platinum salt by heating.

In view of the relatively high cost of such types of catalyst, it is desirable to avoid attrition losses in the lower bed, and for this reason, the catalyst in the lower bed should be arranged so as to undergo little or no movement under operating conditions. Thus, if the catalyst in the lower bed is composed of pellets as indicated in the drawing, these should be sufficiently large in size and/or subject to such mechanical restraint that the bed will not become fluidized under operating conditions. The pellet size in the lower bed will thus be determined in relation to that in the upper bed which is maintained in a fluidized condition, the pellets in the lower bed being larger than those employed in the upper bed in order to avoid fluidization. Generally speaking, pellets in the size range from 1/8" to 1/2" will usually be found satisfactory in the lower bed. Pellets of larger size are usually not desirable because of the unfavourable volume to surface ratio and because of the large interstices between pellets.

Instead of employing pellets, catalysts of other configurations may be employed in the lower bed such as catalytic units consisting of a porcelain framework having rod - like elements coated with a thin film of catalytic alumina, 0.001" to 0.006" in thickness which in turn is impregnated with a relatively small amount such as 1% by weight of finely divided platinum.

Catalysts of high activity, such as the platinum or palladium type catalysts described above, will operate effectively although the entering air-fuel mixture is at a low temperature. In some cases, it will be found possible to introduce the mixture at substantially ambient temperatures or slightly above ambient such as temperatures of 200°—300° F. In any case, it is contemplated that the maximum temperature to which the combustion air entering the lower bed is to be preheated is of the order of 600° F. The combustion air may be readily preheated to such temperatures, and at such temperatures may be easily handled and distributed throughout the area of the lower catalyst bed by such means as a perforated plate distributor as shown.

A network of fuel distributing lines 7 is disposed within the lower bed of catalyst adjacent the bottom thereof for introducing a minor proportion of the total fuel. If desired, the fuel to be oxidized in the lower bed could alternatively be premixed in the combustion air entering the bottom of the chamber through line 5. The method of distribution shown, however, is generally to be preferred. The amount of fuel thus introduced into the combustion air entering the lower bed should be adjusted as previously stated, to provide an elevation in the air temperature to that required for stable operation of the upper fluidized bed, this temperature being generally in the range of from 900°—1500° F. and more usually in the range of from 1000°—1200° F. This elevation in temperature of course results from the heat released by the catalytic oxidation of the fuel occurring in the lower bed.

Between the first and second bed, separating means may be provided such as shown in the drawing and designated generally by the reference numeral 8. Such means may take the form as shown of a series of U-shaped channels 9 extending across the bed, spaced from one another so as to form a series of slots 10 to permit the passage of gases from the first to the second bed. Slots 10 are in turn provided with caps in the form of inverted U-shaped channels 11. This assembly serves chiefly to prevent the relatively small particles in the upper bed from migrating to the lower bed and vice versa and to some extent helps to promote the uniform flow of the effluent gases from the first bed into the second. In some cases it may be found desirable to dispense with the separating means between the upper and lower bed. For example, the lower bed may consist of a layer of relatively large size pellets, of such size as to undergo at the most relatively limited vibration under the influence of the upwardly flowing gas stream, while the second bed is made up of a superimposed deeper layer of pellets, relatively smaller in size, such that these undergo fluidization at the gas velocities involved. Also, of course, other means than that shown may be employed for effecting separation between the

two beds.

The second or upper bed of catalyst is made up of a plurality of pellets or particles 12 smaller in size than pellets 6 in the lower bed. This catalyst is of relatively lower cost and of lower activity than that in the lower bed. Instead of a catalyst containing platinum or palladium for example, the catalyst in the upper bed may consist of less active oxidation catalysts such as catalysts containing silver, copper, nickel, or manganese, preferably distributed in finely divided condition upon carriers consisting of activated metal oxides such as activated alumina or another similar activated oxide mentioned above. For example, a catalyst of good activity, although considerably lower in activity than the corresponding platinum or palladium containing catalysts, may be prepared by impregnating pellets of activated alumina with a mixture of copper and chromium, or of silver and chromium, (preferably by dipping the pellets in solution of nitrates of the metals followed by drying and thermal decomposition of the nitrates) so as to deposit e.g. from 3% to 6% by weight of total metal on the alumina (based on the weight of the alumina pellets).

Such lower activity, lower cost catalysts, operate effectively in the system illustrated only when maintained at a relatively high level of temperature and when the inlet temperature to the bed is likewise maintained relatively high, namely over 900° F. and preferably over 1000° F. The maximum permissible operating temperature of such catalysts will vary somewhat but in most cases should not exceed from 1600°—1800° F. Higher temperatures than this cause repid decline in the activity of the catalyst and eventual complete loss of any significant activity.

The size of the catalyst particles or pellets in the upper bed should be, as stated, such that under the conditions of operation the bed is maintained in a fluidized condition. Briefly, the preponderance of particles will be within the range of from 0.06" to 0.15". Minimum fluidization velocities to maintain pellets of this size range in a fluidized state range generally from 2000 to 6000 standard cubic feet per hour at bed temperatures of the order of 1200° to 1500° F.

The phenomenon of fluidization is of course in itself well known. In the fluidized condition, the bed of particles, under the influence of the upwardly flowing gas stream passing through it is expanded to an extent such that the individual particles become as it were disengaged from one another and circulate freely throughout the bed in much the same way that convection currents circulate in a boiling liquid. The bed as a whole, as a matter of fact, is pseudo-liquid in its characteristics, having a turbulent upper surface which is indicated in the drawing by the letter L, and exerting a pseudo-hydrostatic pressure on the walls and the bottom of the container.

Adjacent the bottom of the fluidized bed, a second series of fuel distributing tubes 13 is provided to admit the major portion of the total fuel which mixes with the preheated combustion air from the lower bed. A substantial portion of the volume of this bed is occupied by tube bundle 14 to accommodate the circulation of a fluid to be heated. The vertical arrangement of the tubes as shown has been found in some respects preferable in that it produces a minimum interference with the uniform fluidization of the bed.

The various sections of the tube bundle as illustrated in Figs. 1 and 2 may be connected in series or in parallel, or portions in series and other portions in parallel as desired, depending upon the particular type of heating system and the fluid to be heated. As shown in Figs. 1 and 2, the fluid to be heated enters the tube bundle through line 16 and is distributed through a suitable system of headers (not shown) which may be incorporated in the space 17. The heated fluid may be collected in a similar series of headers (not shown) accommodated in the space 18 and withdrawn to the point of utilization or for further heating by line 19.

Any desired fluid of course may be circulated through the tube bundle 14. Thus the system may be employed for heating water, for the generation and/or superheating of steam, or for the heating of other fluids such as for the heating of liquid petroleum as is common in oil refineries.

As shown in Fig. 1, combustion air is supplied to the system by means of a blower 28 which introduces air at the rate required to fluidize the upper bed by line 5 which may be controlled by valve 5a. The fuel supply is introduced from main supply line 29 and flows by valved branch line 30 into a header 31 which supplies the system of tubes 7 in the lower bed, and also flows by valved branch line 32 into a header 33 which supplies the system of tubes 13 in the upper fluidized bed.

In the system shown in Fig. 1 the necessary (if any) preheat for the combustion air supplied by the blower 28 is provided by means of a small auxiliary burner 34 supplied with combustion air by an auxiliary blower 35 and by fuel through branch line 36. Hot combustion gases from burner 34 flow by line 37 to be mixed with the stream of combustion air in line 5 to produce a mixture temperature not higher than 600° F. It is thus apparent that the auxiliary burner 34 is required to supply only a small fraction of the total heat released in the main portion of the system, such as 5% to 10%.

Instead of a system shown in Fig. 1, one such as that shown in Fig. 3 may be employed where instead of employing an auxiliary burner to supply the necessary preheat for the combustion air, this is supplied instead by

means of an air heater which is incorporated in a heat exchange system beyond the fluidized bed.

Referring now to Fig. 3, it may be seen the arrangement of the two catalyst beds is substantially identical to that shown in Figs. 1 and 2, these being contained in a chamber designated generally by the reference numeral 19*a* and having refractory lined walls 20. The lower bed of catalyst 21 is supported on a perforated distributing plate 22. As previously described with reference to Figs. 1 and 2, the catalyst in the lower bed is made up of pellets of such size or otherwise constructed or arranged that they undergo little or no movement under conditions of operation and are composed of catalyst of relatively high activity.

The second bed of catalyst 23 is made up of catalyst pellets of relatively lower activity and of such size that they are maintained in a fluidized condition. Separating means, designated generally by the reference numeral 24, consisting of channel members as described with reference to Figs. 1 and 2, is employed between the upper and lower beds.

Fuel is supplied to the two beds through a main supply line 25, valved branch line 26 which supplies the network of distributing tubes 27 in the lower bed, and through valved branch line 28*a* which supplies the network of fuel distributing tubes 29*a* in the upper bed. A tube bundle 30*a* is disposed in the upper bed to accommodate the circulation of the fluid to be heated.

In the embodiment shown in Fig. 3, conventional heat recovery units are disposed following the fluidized bed from which the gases may leave at temperatures varying between about 1000° and 1600° F.

The first of these heat recovery sections consists of a tube bundle 31*a* over which the hot gases leaving the fluidized bed pass on their way to stack as indicated by the broken line arrows.

A second heat recovery section consisting of a tubular air heater designated generally by the reference numeral 32*a* is provided. As may be seen the air heater consists of a plurality of tubes 33*a* through which the hot products of combustion leaving the tube bundle 31*a* pass on the way to the stack. Combustion air supplied by blower 33*b* enters the air heater through line 34*a* and is circulated over the tube surfaces in a circuitous path provided by baffles 35*a*.

Combustion air leaving the air heater is conducted by means of duct 36*a* to the distributing plate 22 through which it enters the lower bed of catalyst. In the air heater, the combustion air may be preheated to temperatures of the order of from 200°—500° F., which, in the case of the active catalyst in the lower bed is sufficient to insure stable operation and to maintain the lower bed within its effective range of operating temperature.

The water, or other fluid to be heated, is introduced into the system by line 37*a* and circulating pump 38 from which it enters the convection tube bundle 31*a* where it may be preheated and then enters the tube bundle 30*a* by line 39 where it is further heated by the absorption of the heat released in the fluidized bed of oxidation catalyst. In a case of the generation of steam, for example, the convection bundle 31*a* may be employed as a preheater and steam generation coil while in tube bundle 30*a*, if desired, super heating of the steam may take place. Alternatively, the convection coil 31*a* may be used entirely as a preheater, while the tube bundle 30*a* in the fluidized bed may be employed as a steam generating coil. The heated fluid is withdrawn from the system by line 40.

In the embodiment shown, the tube bundles 30*a* and 31*a* are shown as connected in series with the use of forced circulation.

In the system shown in Fig. 3, which is more particularly adapted for systems large in size, the use of a preheat burner is obviated since the necessary preheat of the combustion air before entering the lower bed is supplied by means of air heater for transferring heat from the outgoing gases to the incoming combustion air. Thus, in Fig. 3 all the fuel burned in the system is burned catalytically in the two beds.

The two-bed system as described above greatly facilitates the operating flexibility of the upper fluidized bed of catalyst since the degree of preheat of the combustion air entering the fluidized bed may be controlled at will by varying the proportion of fuel introduced into the lower bed which of course upon oxidation in the lower bed will raise the entering temperature of the combustion air entering the upper fluidized bed. By making readily available combustion air at varying desired degrees of preheat, the system permits the operation of the fluidized bed over a wider range of operating temperatures which in turn permits greater variations in the capacity of the unit and also greater variations in the skin temperature of the tubes immersed in the bed.

Since no heat exchange surface, or very little, is associated with the lower bed, the heat generated therein by catalytic oxidation of the fuel on the surface of the catalyst goes entirely to heat the combustion air, and thus the temperature of the effluent from this bed will respond sensitively to any decrease or increase in the amount of fuel introduced into the lower bed and oxidized therein. In contrast, large amounts of heat exchange surface are associated with the upper, fluidized bed and a substantial portion of the heat generated both in the lower bed and in the fluidized bed itself is absorbed by the fluid accommodated by the tubes or other heat exchange means

immersed in the upper bed. The operating temperature of the fluidized bed is in a large measure controlled by the skin temperature of the tubes immersed therein.

Since substantially all the combustion air and only a minor proportion of the fuel under ordinary operating conditions is introduced into the lower bed, the air-fuel mixture in the lower bed will of course ordinarily contain a large excess of oxygen over that required to oxidize the fuel added to the lower bed. In the interest of high efficiency, it is preferable to introduce sufficient fuel into the upper bed so that the air-fuel mixture in the upper bed contains as low a percentage of excess air as is feasible. Thus, desirably, the excess air in the air-fuel mixture in the fluidized bed should be controlled within the range of from about 5% to 20%.

Suitable fuels for introduction into the lower bed include any of the usual gaseous or liquid fuels. Uniform distribution of the fuel in the air stream is of course desirable. In the case of liquid fuels, fine subdivision, as by atomization nozzles, is desirable to insure uniform distribution and intimate contact between the fuel and catalyst. In the upper bed, gaseous and liquid fuels may also of course be employed, taking similar precautions for uniform distribution. In some cases also, very finely divided solid fuels such as very finely powdered coke or coal may be introduced and oxidized in the upper bed.

EXAMPLE.

In this example, a system substantially as shown in Figs. 1 and 2 was employed except that no separating means was employed between the upper and lower beds of catalyst. The catalyst chamber was rectangular in cross-section having a cross-sectional area of 1.35 square feet.

The lower bed of catalyst was supported upon a perforated stainless steel sheet, and consisted of 20 pounds of pellets, cylindrical in shape and having a diameter and length of approximately $\frac{3}{8}''$. These pellets were contained in a bed approximately $3\frac{1}{2}''$ in thickness and were composed of activated alumina impregnated with approximately 0.6% by weight of finely divided platinum.

The upper bed of catalyst consisted of 70 pounds of cylindrical pellets $\frac{1}{8}''$ in diameter and length to make up a layer approximately 17″ in thickness which rested directly upon the layer of $\frac{3}{8}''$ pellets. The pellets in the upper layer consisted of activated alumina impregnated with 1.7% by weight of chromium and 3.3% by weight of copper deposited by impregnating the alumina pellets successively with chromium and copper nitrate followed by thermal decomposition of the nitrates.

Immersed in the upper layer were 61 lineal feet of 1″ outer diameter tubing providing a surface area of approximately 16 square feet. The tubing was arranged for series flow on a once-through circulation basis. This tubing was arranged in vertical sections substantially as shown in Figs. 1 and 2.

The bottom of the tube bundle in the fluidized bed was arranged 7″ above the top of the lower layer of large pellets, while the top of the tubes are just immersed in the fluidized bed after it underwent an expansion of approximately 15% to 20% on fluidization.

Propane gas was employed as the fuel. Approximately 40 standard cubic feet per hour, or about 10% of the total fuel, was burned in a small auxiliary burner to provide the hot combustion gases which were mixed with 9400 standard cubic feet per hour of combustion air to provide a preheat temperature of approximately 520° F. Approximately 100 standard cubic feet per hour of propane or 30% of the total fuel was introduced through the network of distributing tubes provided for this purpose into the lower bed. The remainder of the propane or about 220 standard cubic feet per hour was introduced into the upper bed through the distributing tubes provided in the lower portion thereof, Under these conditions, the amounts of excess air passing to the stack was about 16%.

Oxidation of the propane in the lower bed raised the air temperature to approximately 1070° F. while the average bed temperature of the second bed was approximately 1350° F. Three hundred pounds per hour of water (entering temperature 60° F.) was circulated through the coils immersed in the fluidized bed which was converted into superheated steam at a pressure of 5 pounds per square inch gauge pressure and a temperature of 495° F. Total heat release in the system was 784,000 BTU/hr. of which approximately 60% occurred in the fluidized bed. Approximately 376,000 BTU/hr. were absorbed in the water circulated in the tubes immersed in the fluidized bed. The gas exit temperature from the fluidized bed was approximately 1100° F.

It is understood of course that other modifications of the invention than those specifically described are intended to be included within the scope of the appended claims. For example, both beds of catalyst may if desired contain inert material as well as catalytic material. Thus, for example, the fluidized bed may be composed in part of material having little significant catalytic activity for promoting oxidation reactions and composed partly of material having significant oxidative activity. The required minimum level of activity, of course, in the fluidized bed will be necessary to effect substantially complete oxidation of the fuel introduced therein at the range of operating temperatures involved.

What we claim is:—

1. A method for indirectly heating fluids

by catalytically oxidizing a fuel in a bed of catalyst and absorbing heat from said bed characterized by the steps of passing an air-fuel mixture containing a large excess of air over that required to oxidize the fuel through a first bed of oxidation catalyst of relatively high activity, effecting oxidation of said dilute air-fuel mixture in said first bed of catalyst to produce an effluent oxygen-containing gas at an elevated temperature, adding additional fuel to said hot effluent gas and passing the resultant mixture upwardly through a second bed of oxidation catalyst containing catalyst particles of relatively lower activity which are maintained in a fluidized condition by the upwardly flowing gas stream, catalytically oxidizing the additional fuel in said second bed thereby releasing heat in said bed, flowing a fluid in indirect heat exchange with said fluidized bed to absorb heat therefrom and thereby heat said fluid.

2. A method in accordance with claim 1 in which the catalyst making up the first bed is arranged such that it undergoes substantially no movement under operating conditions.

3. A method in accordance with claim 1 or 2 in which the second bed is directly superimposed over the first bed.

4. A method in accordance with any of the preceding claims in which the combustion air is preheated to a temperature not exceeding 600° F. before introduction into the first bed.

5. A method in accordance with any of the preceding claims in which the temperature of the effluent leaving the first bed is controlled within the range of from 900° F. to 1500° F. and preferably in the range of from 1000° F. to 1200° F.

6. An apparatus for indirectly heating fluids according to the process set out in any of the preceding claims comprising a chamber, a first bed of oxidation catalyst within said chamber or relatively high activity so constructed and arranged that the component elements of said bed remain substantially stationary under operating conditions, means to pass an air fuel mixture containing a large excess of air over that required to oxidize the fuel through said first bed of oxidation catalyst to provide for the oxidation of said air fuel mixture in said first bed of catalyst to produce an effluent oxygen containing gas at an elevated temperature, means to add additional fuel to said hot effluent gas, a second bed of oxidation catalyst in the upper portion of said chamber directly superimposed over said first bed and adapted to catalytically oxidise the added fuel in the hot effluent gas as it passes through said second bed, said second bed being composed of particles of an oxidation catalyst of relatively lower activity of such size as to undergo fluidization under operating conditions, and heat exchange means disposed within said fluidized bed to accommodate the circulation of a fluid to be heated.

7. An apparatus in accordance with claim 6 including fuel distributing means arranged in the lower portion of the first bed and additional fuel distributing means arranged in the lower portion of the second bed.

8. An apparatus in accordance with claim 6 or 7 in which the first and second beds have substantially the same cross-sectional area in the direction of gas flow and communicate with one another at a multiplicity of points at their interface so that effluent gases from the first bed are distributed uniformly throughout the area of the second bed to promote uniform fluidization thereof.

9. A method for indirectly heating fluids substantially as hereinbefore described with reference to the accompanying drawings.

10. An apparatus for carrying out the method claimed in claim 9 substantially as hereinbefore described with reference to the accompanying drawings.

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Leamington Spa: Printed for Her Majesty's Stationery Office, by the Courier Press.—1958.
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.

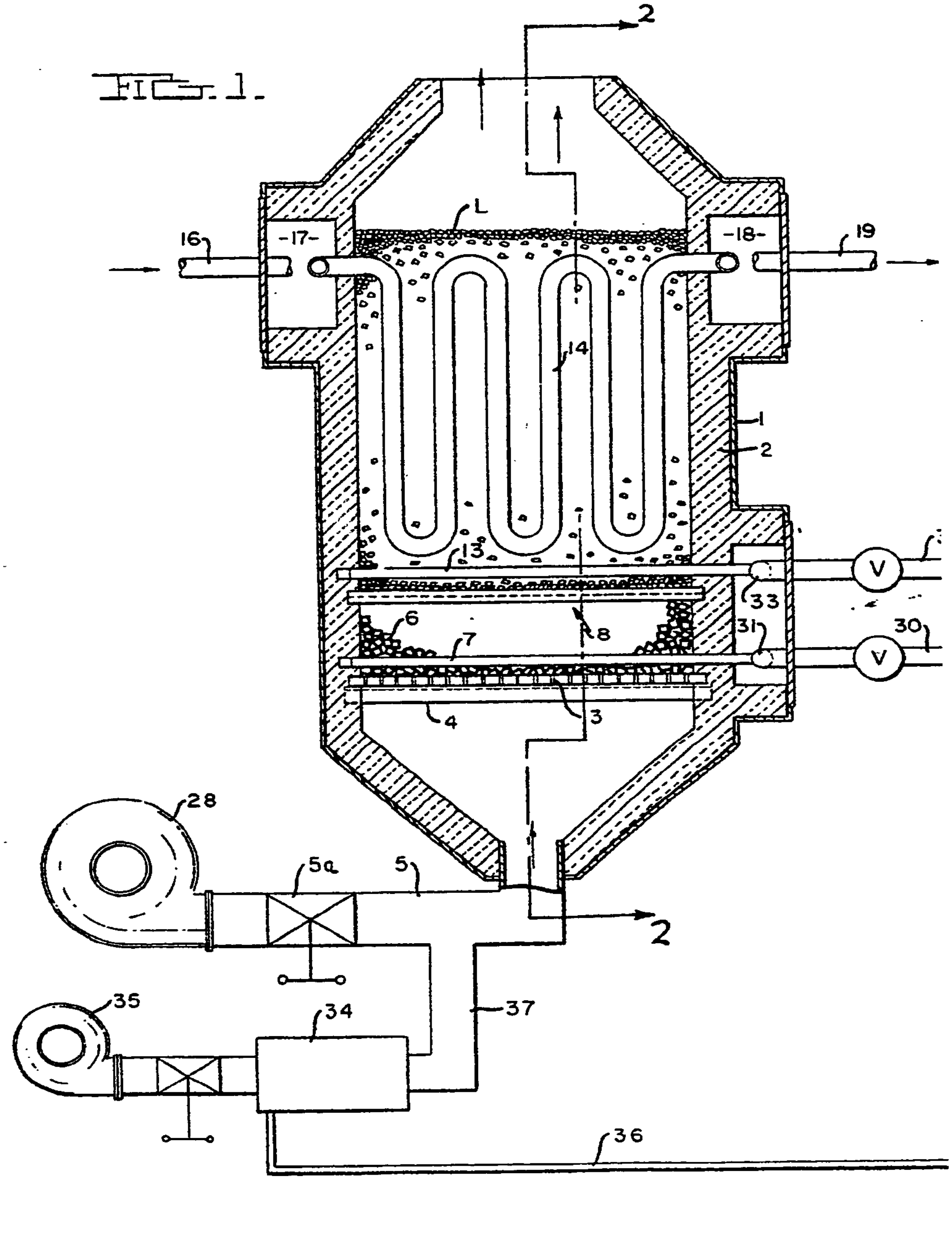
FIG. 1.
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797,574 COMPLETE SPECIFICATION
2 SHEETS

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SHEET 1

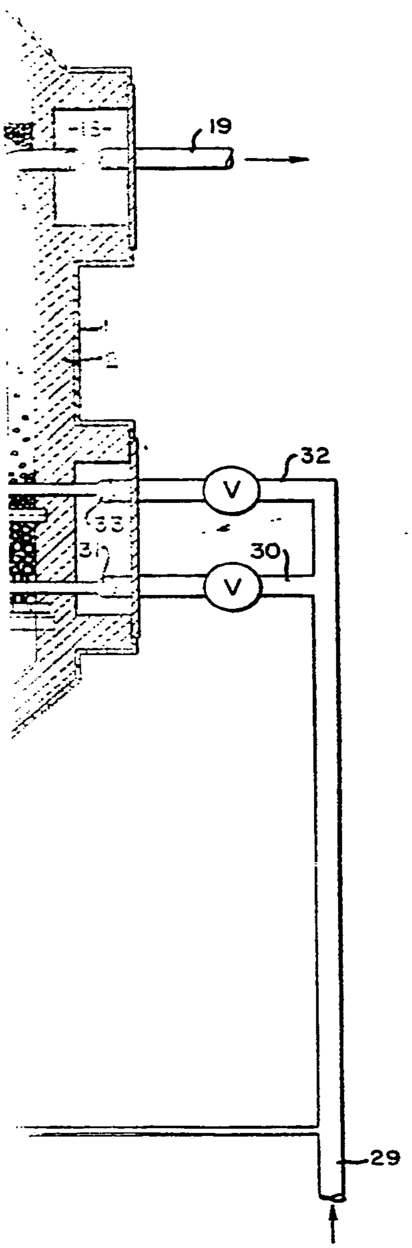
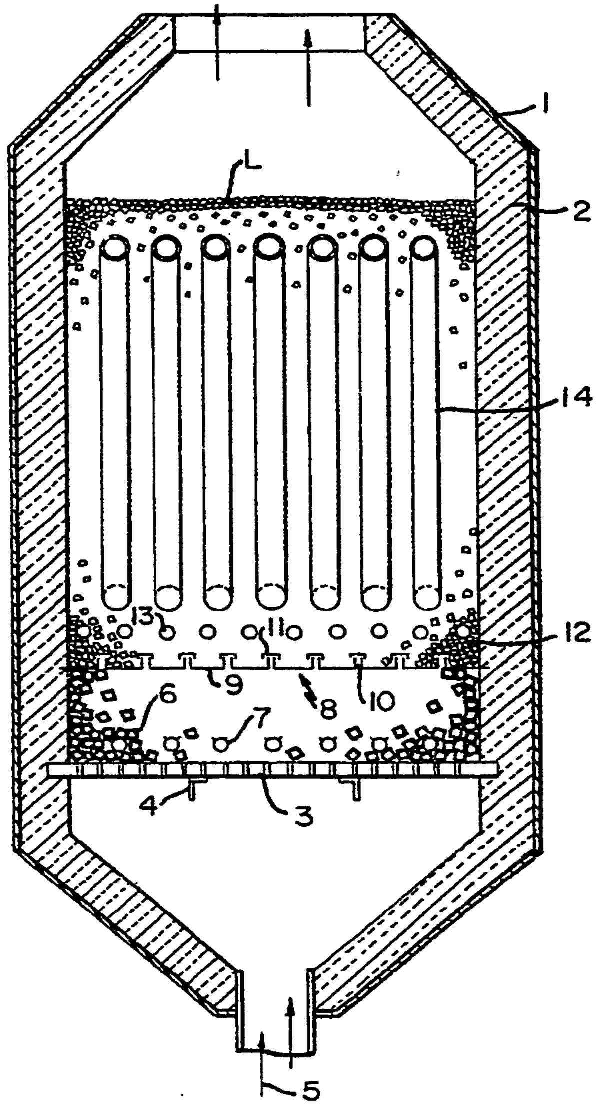


FIG. 2.



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SHEET 1

FIG. 1.

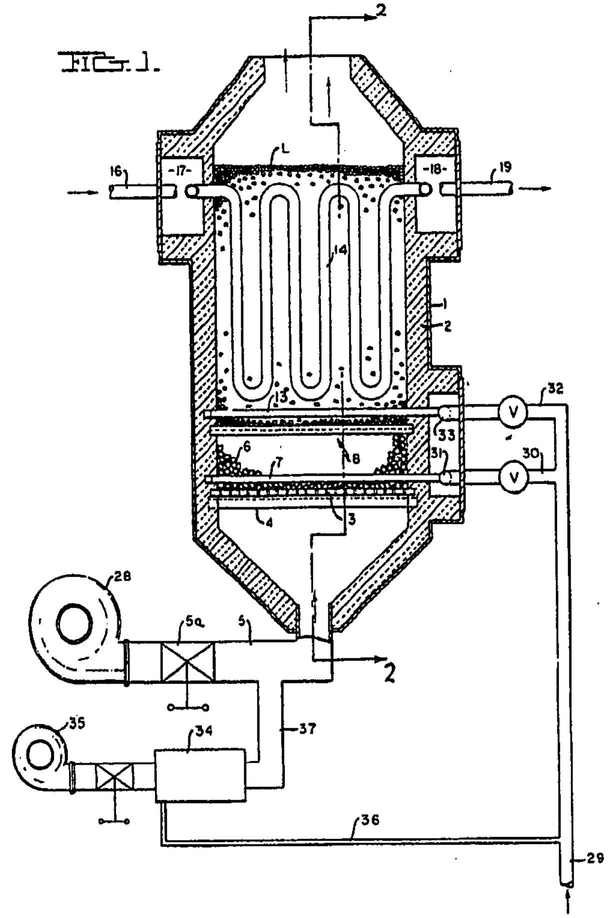


FIG. 2.

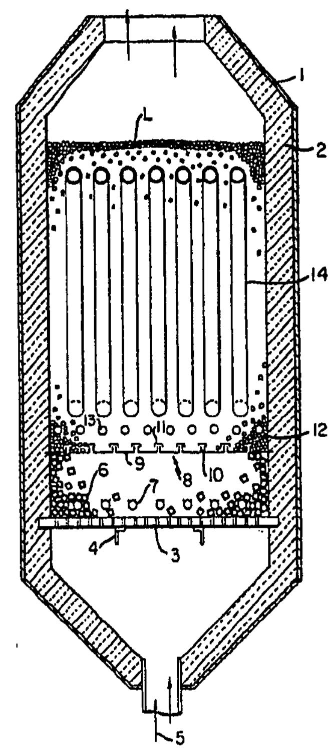
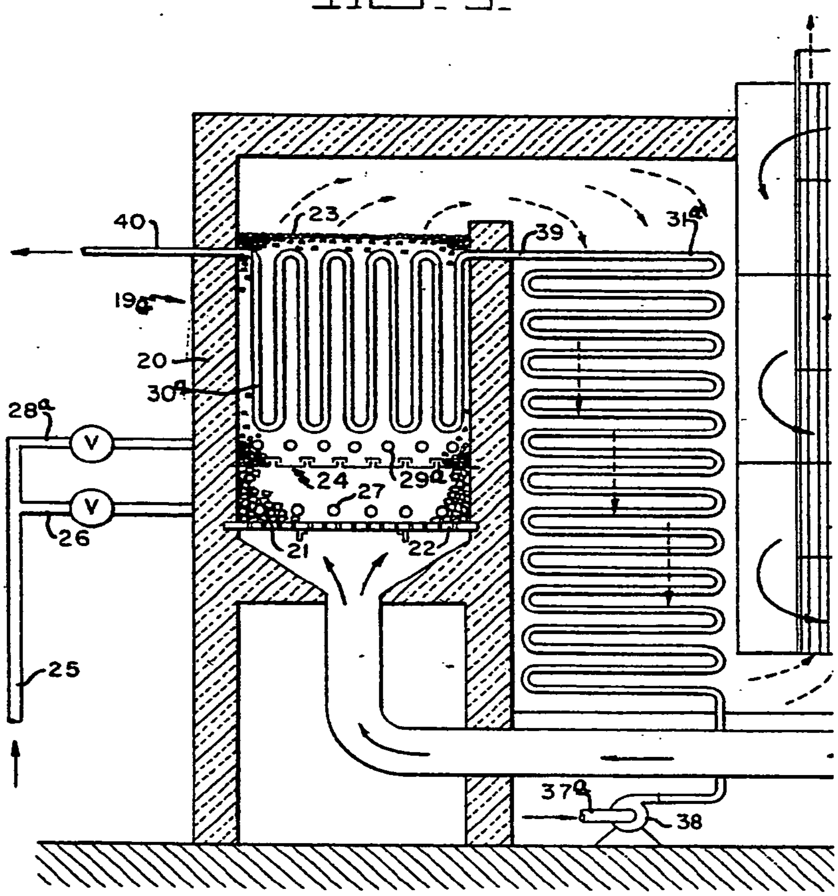


FIG. 3.



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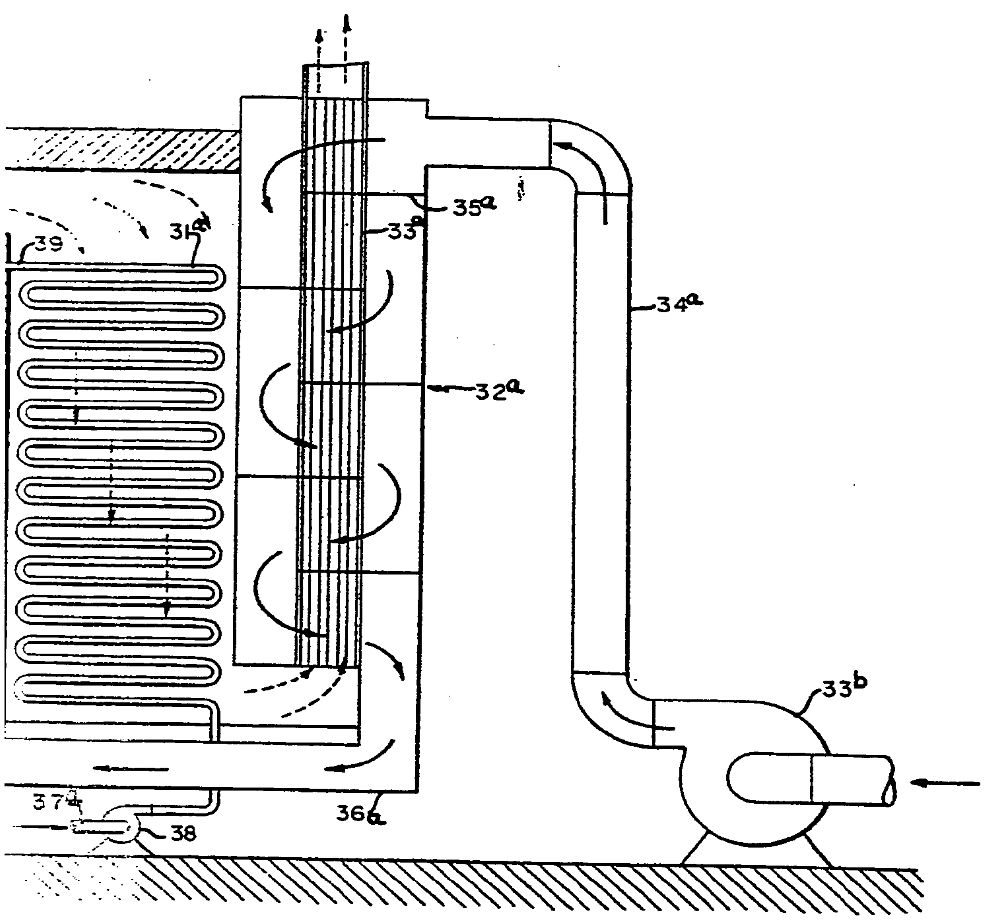
2 SHEETS. This drawing is a reproduction of the Original on a reduced scale.
SHEET 2



797,574 COMPLETE SPECIFICATION
2 SHEETS. This drawing is a reproduction of the Original on a reduced scale.
SHEET 2

FIG. 3.